July 1948

ET-258

United States Department of Agriculture
Agricultural Research Administration
Bureau of Entomology and Plant Quarantine

FIELD-MODEL AEROSOL MACHINES

By A. H. Yeomans
Division of Control Investigations

Field-model aerosol machines were developed during World War II. These machines release a foglike aerosol containing insecticide, which drifts with the wind over large areas. Under good conditions one of these machines can treat 50 acres per hour with one man as operator.

Since aerosols remain airborne longer than sprays, flying insects collect more of the insecticide on them than do stationary insects. Aerosol particles, being smaller than spray particles, penetrate foliage and small openings better.

Aerosol machines are best adapted to applying small quantities of insecticide over large areas, and for this reason a concentrated solution of insecticide is most suitable for use in them. Owing to the reduced weight of concentrated solutions, aerosol machines can be used over areas where heavier equipment for applying dilute sprays would have difficulty in moving. The aerosol method shows promise for applying DDT to control the tarnished plant bug on peach trees, *Lygus* bugs and leafhoppers on alfalfa, flea beetles on beets, whiteflies on eggplant, armyworms on truck crops, and as a temporary control of various species of adult flies and mosquitoes.

One disadvantage of the aerosol method of applying insecticides out of doors is the requirement of suitable weather conditions. A surface inversion in the air is necessary to keep the aerosol close to the ground. The temperature near the ground should be 1° F. cooler than at 6 feet above to indicate a suitable surface inversion. This condition usually occurs on clear nights between 1 hour after sunset and sunrise and sometimes during the day when the ground is wet or cold. A light wind of from 1/2 to 8 m.p.h. and steady in direction is also necessary.

The amount of deposit on foliage outdoors depends on the contour of the ground; the density, height, and types of foliage; the particle size of the aerosol; and the wind velocity and surface inversion. Under the best conditions about 50 percent of the insecticide can be accounted for and the deposit extends for about 2000 feet, but in poor weather the loss becomes greater and if the aerosol is released in the heat of the day the appreciable deposit extends less than 100 feet. Under all conditions the deposit tapers off in intensity as the distance from the machine increases. Adult mosquitoes flying through the aerosol have been affected as far as a mile from the release point, even though there is no appreciable deposit at this distance.

A great deal of research has been done to determine the optimum particle size to use under various conditions and how to dispense the aerosol with a

minimum loss of insecticide. Generally the optimum particle size for outdoor applications has been found to be between 10 and 50 microns mass median diameter. The optimum particle size for interior application lies between 1 and 20 microns mass median diameter. Many of the field-model machines are used for treating interiors of warehouses, barns, and greenhouses. Some poor results that have been reported in greenhouse applications were probably due to the use of too large a particle size. Various machines have been developed for producing aerosols of a controllable particle size.

The new aerosol machines utilize old methods of breaking up the liquid into small particles, but in addition take advantage of other factors. The physical qualities of the liquid to be broken up can be utilized. If a volatile liquid is used, the particles shrink as soon as released. To prevent excessive drift and wastage of insecticide, it is necessary to limit the shrinkage by adding a small amount of liquid of low volatility to the aerosol formula. A volatile liquid, such as xylene, in the insecticide solution evaporates rapidly, leaving the liquid of low volatility, such as a heavy oil, and the insecticide to maintain the proper particle size.

There are three general types of field-model aerosol machines--nozzle-type, thermal, and shattering.

Nozzle-Type Machines

Gas Atomizers

The gas atomizer is the most widely used field machine for producing aerosols. As in all atomizers, the size of the particles dispersed varies with the velocity of the gas and the surface tension of the liquid. The particle size increases rapidly with viscosity of the liquid if the amount to be broken up is large compared with the amount of gas used to break it up.

The <u>cold-air atomizer</u>, such as a paint sprayer, has not been used to produce aerosols on a large scale, because it is difficult to overcome the viscosity of large quantities of liquid. Small quantities of oil solutions can be broken up into aerosols in this manner by adding low-viscosity and volatile solvents. When a DeVilbiss type WV air gun was used with a setting of 1 gallon per hour, a mixture of equal parts of deodorized kerosene and acetone produced particles of 10 microns mass median diameter and 30 microns maximum diameter. An air pressure of 5 pounds per square inch was used, and the oil-set screw on the nozzle was open six turns and the air screw two turns. Cold-air atomizers are used for producing small quantities of fine sprays in insecticide test work, such as in Peet-Grady chambers, turntable tests, and some wind-tunnel tests. Aerosols produced by this method are heterogeneous in particle size. The minimum particle size that can be produced by this method is about 5 microns mass median diameter. This measurement does not allow for shrinkage due to evaporation after the particle is formed. Some of the new mist blowers use the air velocity to produce very fine sprays in the aerosol range, but they are not generally classified as aerosol machines.

The <u>hot-gas atomizer</u> is widely used for producing aerosols, being preferred to the cold-air type because the heat reduces the viscosity of oil solutions. To some extent the heat partially vaporizes the oil, which condenses into fine particles on contact with cold air. The gasoline-engine exhaust machine is one of this type on which considerable work was done during the war. (Fig. 1.) In properly designed exhaust aerosol machines the oil-injection tube is exposed for several inches to the hot exhaust gases to lower the viscosity of the oil solution. For this reason the aerosol nozzle must be attached fairly close to the engine. The exhaust gas is increased to the maximum velocity by using a venturi tube and injecting the oil solution into the gas at the constriction of the venturi. The most satisfactory method of injecting the oil solution into the gas is through a large opening at low pressure. If the oil solution is injected into the hot gas through small openings, clogging and coking will result.

In this type of apparatus the particle size can be reduced by increasing the speed of the engine, and by decreasing the flow of liquid. The capacity of this type of generator depends on the size of the gasoline engine. The capacity, in gallons per hour, is roughly about one-third the brake-horsepower of the engine. The minimum constriction to use on the exhaust without building up too much back pressure is, in square inches, about 1/300 of the brake-horsepower.

This method of producing aerosols is economical, and the cost of the equipment is negligible, if the motor is already on hand. When oil solutions are used, particle sizes from about 2 to 3 microns diameter up to coarse sprays can be produced. Some of the disadvantages are the difficulty in breaking up water solutions, and the possibility of thermal decomposition of the insecticide.

This type of apparatus was used successfully during the war on jeep and aircraft engines (Rice <u>et al</u>. <u>2</u>). Since the war smaller engines down to 1-1/2 hp. have been equipped with exhaust nozzles for indoor use or under canopies (Yeomans and Bodenstein <u>3</u>). For larger areas this method is well adapted for tractor engines.

A method of atomizing a liquid by heating air and pumping it through a specially designed nozzle was perfected by a commercial firm. A 6-1/2 hp. gasoline motor is used to drive a rotary-type air pump that delivers about 150 cupic feet per minute of air. (Fig. 2.) The air passes through and is heated by a gasoline-burning combustion chamber fired by a constant spark and regulated to maintain a temperature of 900° F. The hot air then passes through special nozzles into which the insecticide solution is injected. A metering valve is used to regulate the flow of insecticide solution through the nozzle, and in this way the particle size is regulated. The insecticide pump, a centrifugal type, has capacity enough to supply 50 gallons per hour to the nozzles and to circulate 200 gallons per hour back to the insecticide tank to keep the solution agitated. In the specially designed nozzles the liquid and a small quantity of air are released at the base of the nozzle with a rotating motion. Most of the air comes in contact with and breaks up the liquid at the tip of the nozzle.

This machine can be used without heat and the liquid is then atomized into a very fine spray by the air blast. When the air is heated to 900° F., the viscosity of the oil is reduced and the oil partially vaporized, and in this way the particle size is greatly reduced. With a solution of 2/5 xylene and 3/5 SAE 10 W motor oil, the particle size obtained with the heat on ranged from 5 microns mass median diameter with the control-valve setting of 10 gallons per hour to about 50 microns with the maximum setting. Without heat the particle size ranged from about 25 to 65 microns mass median diameter. Different particle sizes would be obtained by changing the characteristics of the solution, such as using liquids of different surface tension and viscosity. This machine consumes about 1/2 gallon of gasoline per hour with heat off and about 3 gallons per hour with heat on.

Hot gases produced by combustion of chemicals have been used to break up insecticide solutions. One such method is use of the Comings candle,1/ a small container in which highly combustible material is placed in one compartment and the insecticide solution in another. The combustion of the material in the one end causes hot gases to escape through a venturi tube. The venturi tube passes through the insecticide solution and as the hot gases escape through the venturi a plug is melted and the insecticide solution is drawn into the hot gases and is thereby broken up into aerosol particles. The particle size was very small on the test models (about 1 micron diameter), but the size could be increased by increasing the size of the oil flow hole. This method is not economical, but in some cases might be suitable in warfare.

Steam has been used for some time to break up large quantities of oil. Columbia University, working in cooperation with the Bureau of Entomology and Plant Quarantine under OSRD funds, developed a pressure-shearing method in utilizing steam to break up oil. This method, called the Hochberg-La Mer method, consists in pumping a mixture of water and the insecticide solution through a coil which is heated in a combustion chamber (LaMer and Hochberg 1). The heat converts the water to steam and lowers the viscosity of oil solutions. The steam pressure causes a shearing action which breaks up the insecticide solution as it issues from large jet openings. The combustion chamber is heated with either gasoline or fuel oil, and the temperature is regulated by a thermostat, which controls the amount of fuel pumped to the burner. A gasoline engine of about 1-1/2 hp. is used to pump the water and insecticide solution, also to furnish air and fuel to the burner, and to furnish a constant spark from its magneto for the burner. The Army model E-12, used by the Bureau of Entomology and Plant Quarantine, is equipped with two plunger pumps, one to pump the water and the other the insecticide solution. (Fig. 3) Each pump delivers about 20 gallons per hour. The water and the insecticide solution are mixed before passing through the heater coils. This machine is equipped with two nozzles, set at a 60-degree angle, both 1 inch long with a 1/8-inch diameter opening. The particle size is controlled by setting the thermostat for temperatures between 300° and 600°F. The pressure developed by the steam ranges from 60 to 120 pounds per square inch. A relief valve is installed in the heater coil line to prevent excessive pressure.

1/ Anderson, L. D., Rogers, E. E., and Latta, Randall. Biological field tests with insecticidal aerosols generated by modified Comings thermal generators. OSRD Interim Report C-16, April 26, 1945.

This machine is arranged so that water alone can be pumped through the heater coil until operating temperature is reached, and also to flush out the heater coils while cooling after use. This arrangement prevents waste of insecticide and reduces the danger of coking and clogging of the coils.

When a mixture of 1 part of xylene in 4 parts of SAE 10 W motor oil was used in a DDT solution, an average particle size of 10 microns was obtained at 600°F., 15 microns at 500°, 20 microns at 400°, and 30 microns at 300°. Less viscous oil solutions produced smaller particle sizes. Insecticide solutions used in this machine should have a higher boiling point than water; otherwise the particle size would be too small to be effective.

This machine operates on the principle of keeping the insecticide solution in liquid form in order to produce effective particle sizes. This machine uses the nearest approach to the principle used in the aerosol bomb of any of the field machines.

There are several variations of this machine. Some of the machines vary the ratio of water to oil-insecticide solution and in this way vary the particle size without changing the temperature. Most of the machines are modifications of the thermal smoke generators used by the military forces. The thermal smoke generators operate at about 900°F. with a pressure of about 60 pounds per square inch, and completely vaporize the oil, which condenses into very fine particles, less than 1 micron in diameter. This size would be ineffective for insect control. In the smoke generators only about 10 percent of water is added to the oil to help flush out the coils. When more water is used, as in the aerosol generators, more fuel is consumed even though the operating temperature is reduced. Because of the greater power required in the aerosol machine, larger motors and better pumps are sometimes necessary when the smoke machines are converted into aerosol machines.

Steam can also be used to break up insecticide solutions in the same way that air or other gases are used in atomizers. A machine to accomplish this is now available. (Fig. 4) It is similar to the thermal smoke generator or pressure-shearing machine, except that water alone goes through the heater coil and is converted into steam. The insecticide solution is by-passed around the heater and injected into the steam through a nozzle. A two-plunger pump is generally used--one for the water and one for the spray solution. This machine is equipped with a 1-1/2 hp. gasoline engine, and has an output of 38 gallons per hour of insecticide solution and an equal quantity of water. The burner uses pressure-atomized fuel oil, which is ignited by an automatic spark from the engine magneto. There are two 50-gallon tanks, one with an agitator for the solution, and the other for water. The average fuel consumption of this machine is 5 gallons of fuel oil and 1 quart of gasoline per hour.

A thermal smoke generator manufactured by the same company has been converted by the Bureau of Entomology and Plant Quarantine to a machine similar to the one described. When a mixture of 3 parts of SAE 10 W motor oil and 2 parts of xylene was used in this machine, a particle size of 100 microns diameter was obtained at 300°F., 65 microns at 350°, 40 microns at 600°, and 20 microns at 800°. This type of machine usually operates between 400° and

900° at a pressure between 80 and 160 pounds per square inch. It also requires higher temperatures to produce the same particle size than the Hochberg-LaMer type, but the insecticide solution has less contact with heat and there is no danger of clogging the heater coils. This method can be used to break up water suspensions and liquids of low boiling point, as well as the oil solutions.

Pressure Nozzles

Another method of producing aerosols is by exerting pressure on liquid. Pressure nozzles are practical only for breaking up liquids of low viscosity. They generally clog more easily than the gas-atomizing nozzles, and under ordinary conditions do not produce so fine a particle as the atomizers. Pressure nozzles, however, are generally simple, small, and inexpensive, and they usually consume less power than the atomizing type. A method of producing aerosols in the field by pressure on liquid is used in South America. The aerosol machine designed in Argentina uses a Ford engine to compress tin tetrachloride in one cylinder and the insecticide dissolved in acetone or similar volatile solvent in another cylinder. (Fig. 5) Both the insecticide solution and the tin tetrachloride are released through a bank of nozzles close together so that the two mix and produce a heavy fog. Another aerosol machine subjects a permanent charge of nitrogen, by hand pump, to pressures between 350 and 1000 pounds per square inch. The nitrogen exerts pressure through a piston to the insecticide solution. This high pressure atomizes the insecticide solution into a super-fine mist or fog as it passes through the turbulence chamber of the fog nozzle.

Rotating Disks

Rotating disks are generally useful in breaking up very viscous materials. A commercial firm has designed and built aerosol machines with rotating disks, a small electrically driven one for indoor use, and a larger gasoline model for field use. These machines have several disks held together at the edge, and the insecticide solution is forced out from between them by centrifugal force as they rotate at high speed. This method of using the disks limits their use to solutions, and viscosity influences particle size more than with the open type of disks. Constricted disks are reported to give finer particles than open ones.

The latest field-model machine uses a 6-1/2-hp. engine to rotate by means of V belts 21 disks 8 inches in diameter at about 6500 r.p.m. (Fig. 6) A high-velocity blower with a capacity of about 4500 cubic feet per minute throws the aerosol out horizontally from the disks. The disks are mounted on a hollow shaft, through which the insecticide solution is drawn by the suction produced by the centrifugal force. A separate supply tank is used and must be mounted at least as high as the disks because the suction is reduced by a strainer located in the supply line. This machine will deliver up to about 250 gallons per hour, and the output can be controlled by a metering valve.

The size of particles issuing from the machine is a function of the output. The minimum particle size obtained with a solution of 2/5 xylene and 3/5 SAE 10 W motor oil was about 40 microns mass median diameter. For smaller particles oil solutions of lower viscosity must be used or volatile solvents added. The base on which the machine is mounted allows a 20° tipback with a 360° rotation. The larger particles produced by this machine compared with other types do not limit its usefulness for field use except in cases where the maximum amount of penetration is required. The indoor electrically driven machine, with a rotation of about 17,000 r.p.m., produces smaller particles, with a mass median diameter of about 10 microns, when using deobase fly sprays.

Thermal Generators

Burning

Burning, or incomplete combustion, has been used to produce aerosols for insect control, but generally has not been adopted where other methods are available. The British have used this method in the field in experimental work with some success. The insecticide is mixed with some slow-burning material and ignited, and the resulting smoke is drifted over the area to be treated. This method has the following disadvantages: The percentage of thermal decomposition of the insecticide is high, the particle size is too small for optimum efficiency, and the smoke is generally irritating. It has been used more widely for indoor than for outdoor applications.

Vaporizing

A great deal of work has been done on vaporizing insecticide solutions and then allowing them to condense to produce aerosols. This method has been used successfully in the laboratory to produce particles up to 25 microns mass median diameter. Generally the particles are too small to be effective and under ordinary conditions are less than 1 micron diameter. The number of nuclei ordinarily found in the air must be reduced to increase the particle size of the aerosol, and the ratio of air volume to rate of vaporization has to be controlled carefully. The chance of thermal decomposition of the insecticide by this method is one of the disadvantages. Moreover, the insecticide must have a boiling point nearly the same as the solution to maintain the same concentration in the aerosol as in the solution. The thermal smoke machines used by the military forces are based on this principle, but when conversion to aerosol machines was first tried little progress was made because the rate of condensation could not be controlled enough to produce effective particle sizes. These machines were later readily converted by using the method of gas atomization.

Shattering Machines

Breaking up liquids by shattering has been used to only a limited extent to produce aerosols. Some tests have been made in which an insecticide was put into grenades and then exploded. The result did not appear practical because of the high cost of the explosive and the small quantities of insecticide dispensed.

Breaker bars and impinging methods of breaking up liquids have not been used for producing aerosols in the field. When pressure nozzles are used in conjunction with breaker bars, nozzle clogging and high viscosity are still problems. This method is used to break up small quantities of water and the less viscous liquids into the aerosol range. It is used on airplanes to produce sprays of particles larger than the aerosol range.

Conclusion

In selecting the proper type of field-model aerosol machine to use, one must consider the original cost, the simplicity of design, the operating cost, the possibility of breakdown of insecticide, the types of solution that the machine will handle, and the range and ease of particle-size control. There is no machine so far that is outstanding in all these points. A selection should therefore be made according to its excellence in the most important features that apply to the job to be done.

Literature Cited

(1) LaMer, V. K., and Hochberg, Seymore.
1945. Hochberg-LaMer aerosol generator - inventors model. (OSRD Report 4901.) U. S. Dept.Com. Off. Pub. Bd. Rpt. 15617. (Processed.)

(2) Rice, R. I., Johnstone, H. F., and Kearns, C. W.
1946. An exhaust aerosol or spray generator for dispersing insecticides. Jour. Econ. Ent. 39: 652-658.

(3) Yeomans, A. H., and Bodenstein, W. G.
1947. An exhaust aerosol generator for 1-1/2 horsepower motors. U. S. Bur. Ent. and Plant Quar. ET-238, 6 pp. (Processed.)

Figure 1.—Exhaust aerosol apparatus mounted on engine of sprayer-duster machine.

Figure 2.—Pumped hot-air type of aerosol machine.

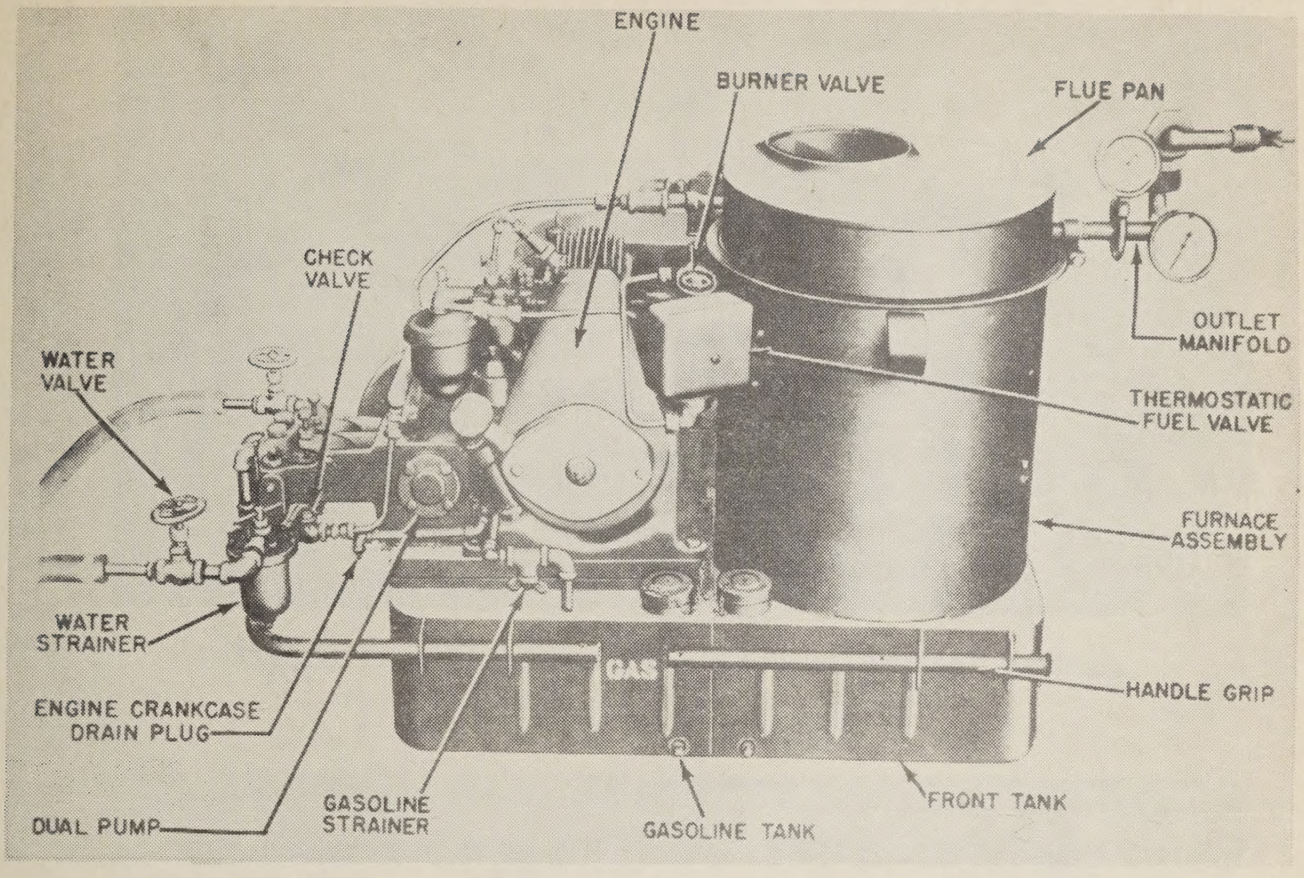

Figure 3.—Pressure-shearing type of steam aerosol machine.

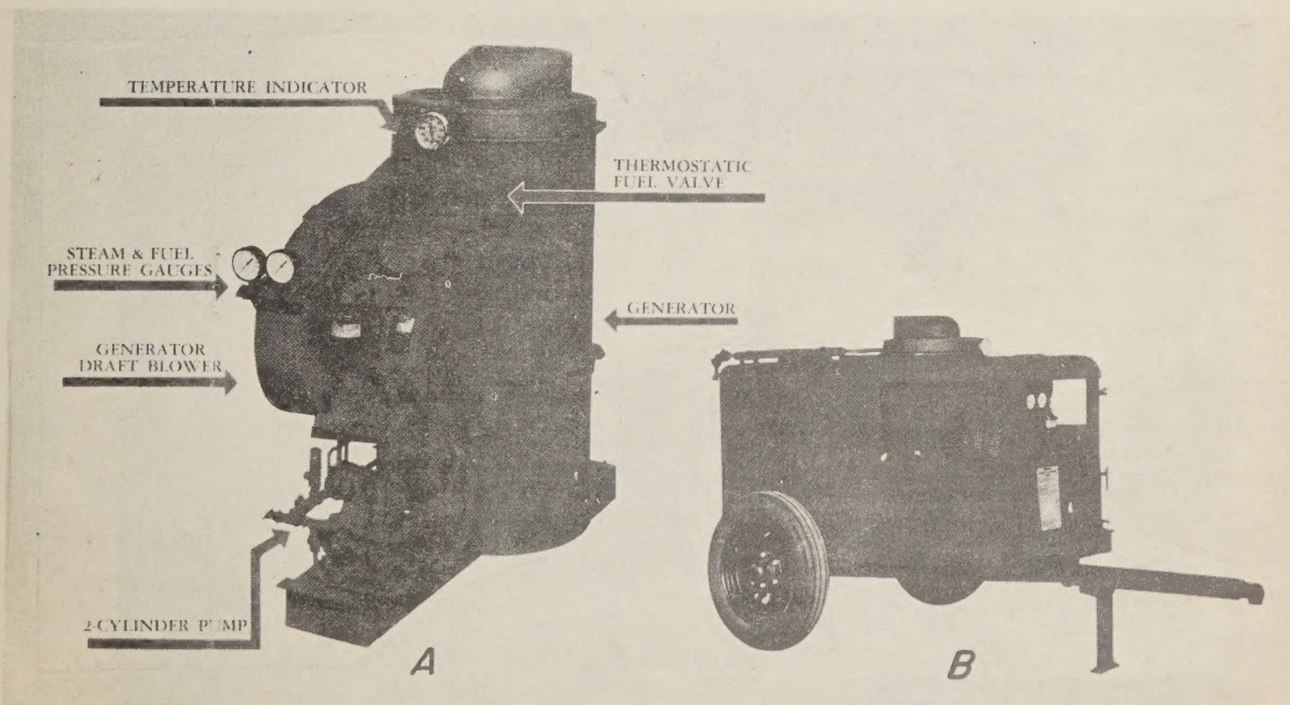

Figure 4.—Steam-atomizing type of aerosol machine: (A) Aerosol generator only, mounted on base but without hood, water tank, or solution tank; and (B) trailer-mounted aerosol generator equipped for towing behind tractor.

Figure 5.--Liquid-pressure type of aerosol machine.

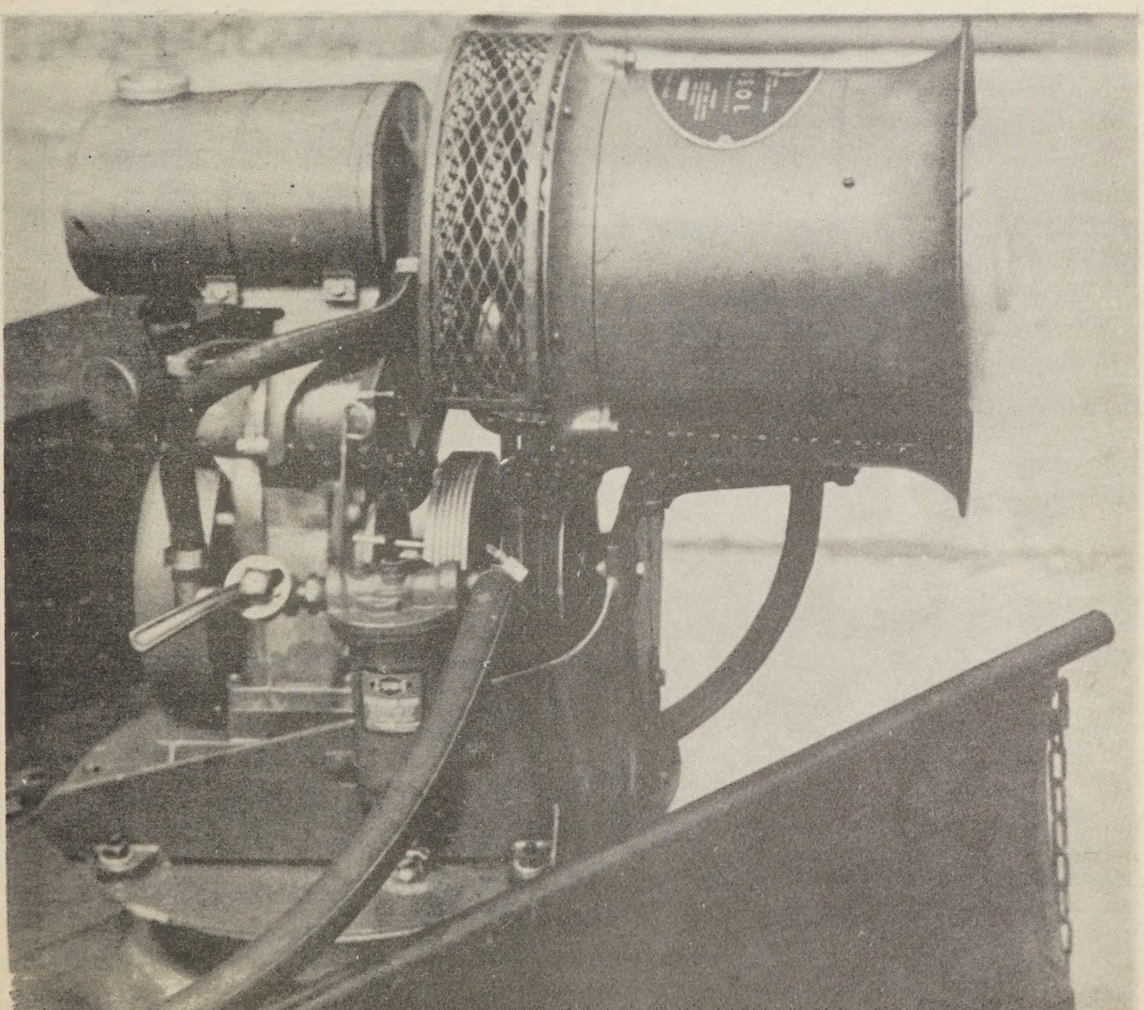

Figure 6.--Rotating-disk type of aerosol machine.